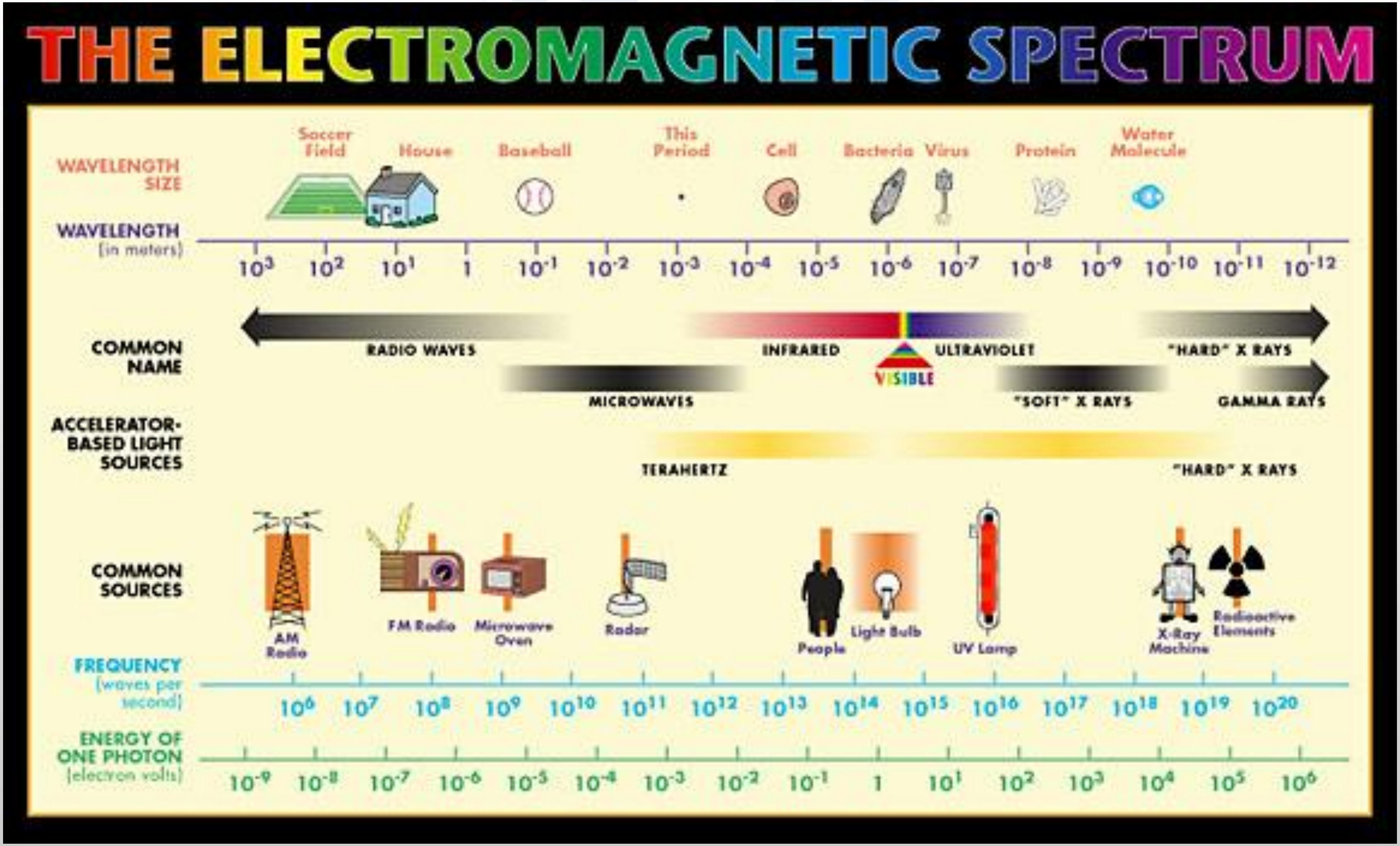
Status and Future of Storage Ring Based Hard X-ray Sources

H. Reichert

EM radiation is an ideal probe for materials properties



Why are Synchrotron X-rays useful for studying Materials?

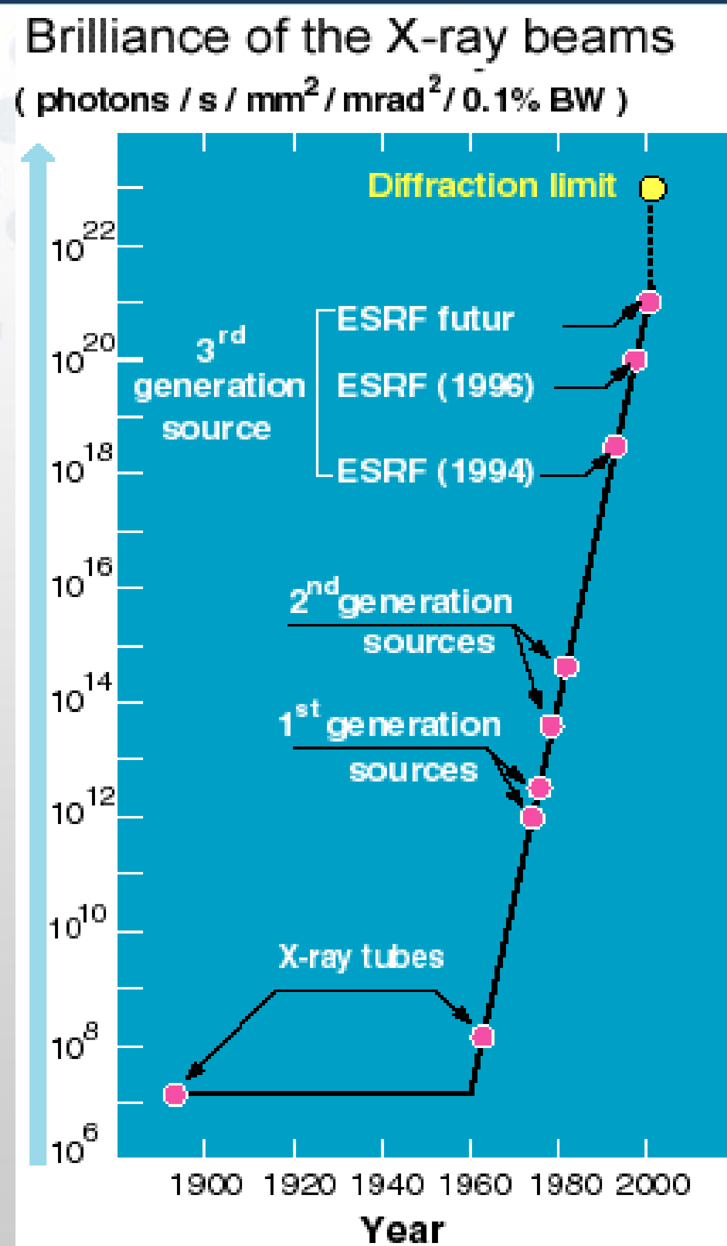
- **EM radiation** produced by accelerating relativistic electrons or positrons, covers about 8 orders of magnitude of the EM spectrum
- **Very intense and Highly polarised**

Wavelength (Å) Diffraction	~ $\rightarrow$	inter-atomic distances structures with atomic resolution
Energy (keV) Inelastic scattering and spectroscopy	>> $\rightarrow$	phonon and electron energies phonon and electron dynamics
Absorption/Scattering Power varies strongly with energy	$\rightarrow$	element specific information
SR is electro-magnetic radiation	$\rightarrow$	magnetic information/structures
Pulsed source	$\rightarrow$	time resolution

Synchrotron radiation is a universal tool, a swiss army knife for studying materials

The success of the ESRF triggered the development of many 3rd generation synchrotron radiation sources around the world

Brilliance



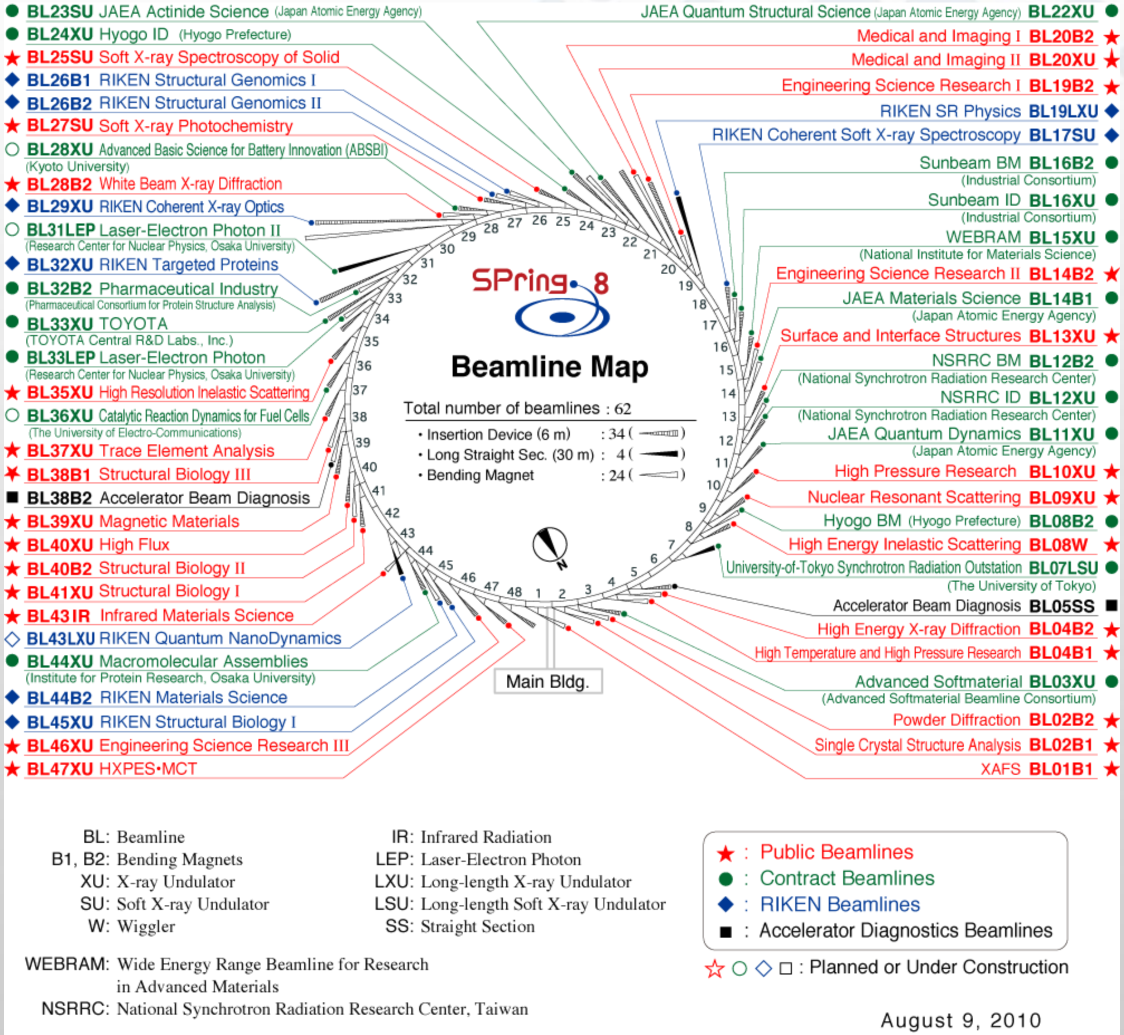
Synchrotrons around the world

Location	Institution
Europe	
Denmark:	ISA (Aarhus).
France:	LURE (Orsay), Soleil (Orsay).
Germany:	ANKA (Karlsruhe), BESSY (Berlin), DELTA (Dortmund), ELSA (Bonn), HASYLAB (Hamburg).
Italy:	Elettra (Trieste).
Spain:	ALBA (Barcelona).
Sweden:	MAX (Lund).
Switzerland:	SLS (PSI) (Villigen).
United Kingdom:	Diamond (Didcot), SRS (Daresbury).
Americas	
Brazil:	LNLS (Campinas SP).
Canada:	CLS (Saskatoon).
USA:	ALS (Berkeley CA), APS (Argonne IL), CAMD (Baton Rouge LA), DFELL (Durham NC), CHESS (Ithaca NY), NSLS (Upton NY), SRC (Madison WI), SSRL (Stanford CA), SURF II (Gaithersburg MD).
Asia	
China (PR):	BSRF (Beijing).
India:	INDUS 1 and 2 (Indore).
Japan:	Photon Factory (Tsukuba), SPring-8 (Nishi Harima).
Russia:	SSRC (BINP) (Novosibirsk).
South Korea:	Pohang Accelerator Lab (Pohang).
Taiwan:	SRRC (Hsinchu).
Australia	
Australia:	Australian Synchrotron (Melbourne).

International Context

- Worldwide: 45 SR/FEL facilities (2008 LBNL/ALS pocket diary)
- New sources: China, Germany, Spain, Sweden, USA..
- The 4 large rings: APS (USA), ESRF (Europe), PETRA III (G), SPring-8 (J)

Spring-8 (8GEV), Harima, Japan



~60 beamlines

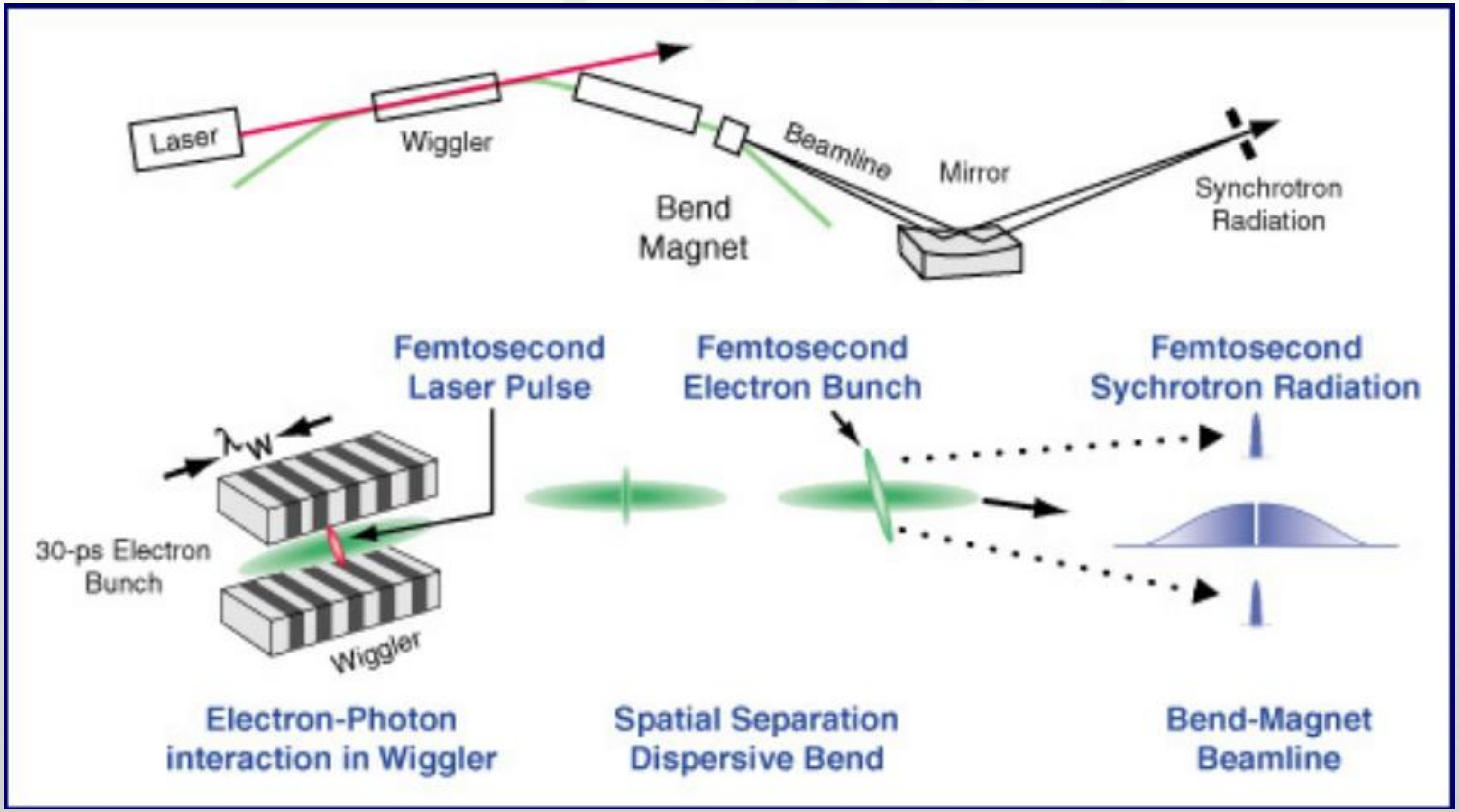
across

all fields of science

Perspectives for Storage Ring Based Sorces

- new sources (NSLS II – BNL, TPS – Taiwan, MAX IV – Lund)
- more beamlines (PETRA III, ALBA, Soleil, DLS, SSRF)
- upgrade of existing sources (ESRF, APS,....)
  - reduction of emittance
  - improved sources (cryo-, sc undulators)
  - smaller x-ray beams (new optics)
  - higher efficiency (new detectors)
  - sophisticated sample environments
  - combination of techniques

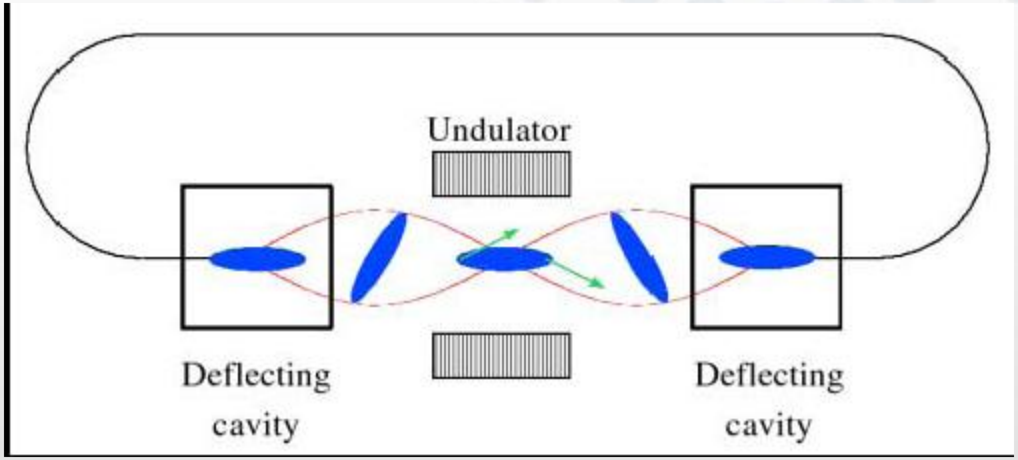
Improvement of time resolution beyond the ps time scale (bunch length) by laser slicing (low energy rings)



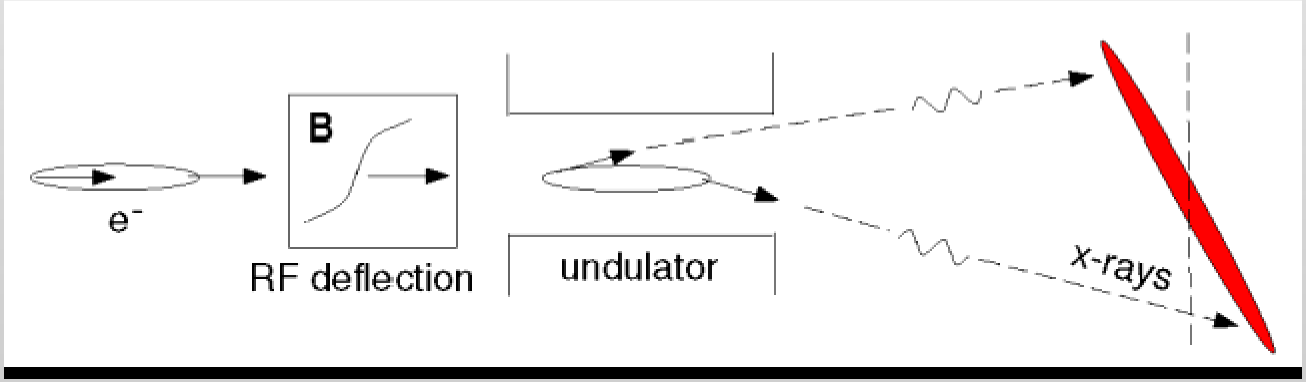
ALS
BESSY
SLS

A. A. Zholents, M. S. Zoloterev, PRL 76 (1996), 912.

Improvement of time resolution beyond the ps time scale (bunch length) by crab cavities (high energy rings)



APS
(upgrade)



Reduction of horizontal emittance by damping wigglers

PETRA III damping wigglers

Damping wigglers

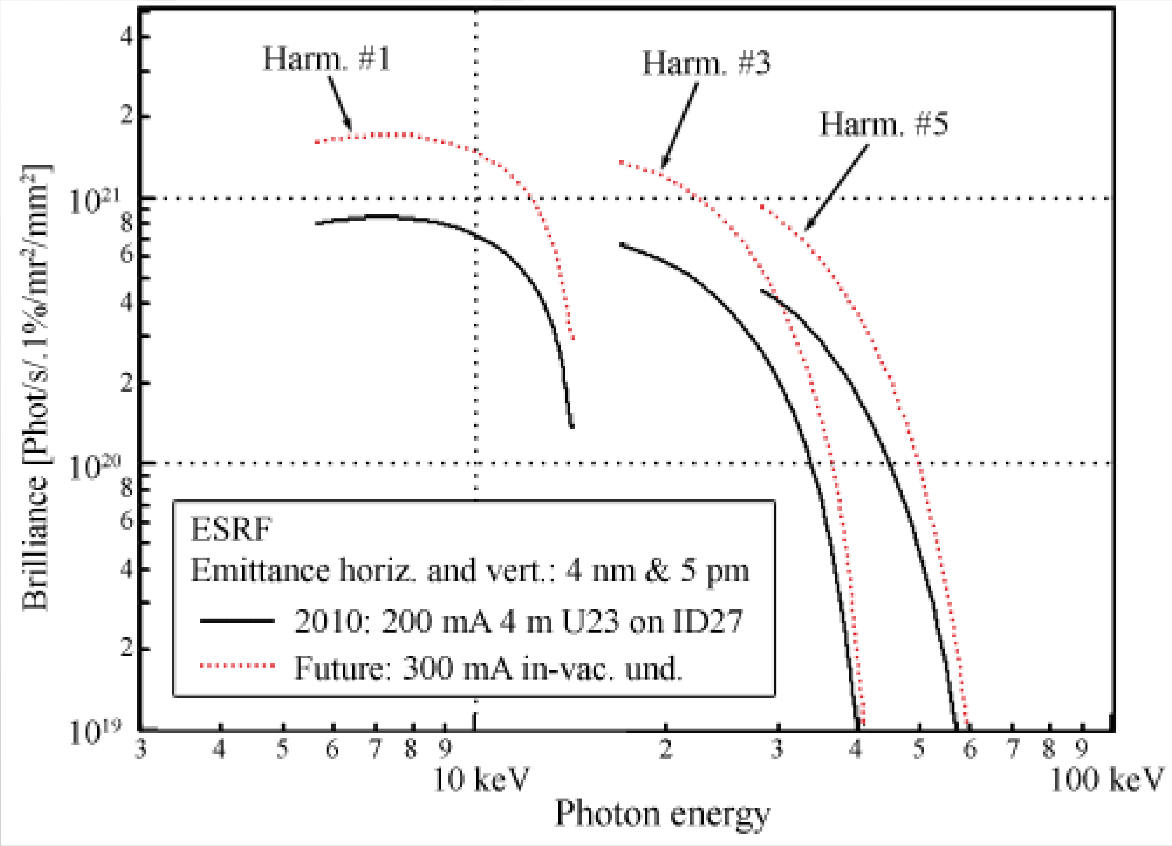
Wiggler period	20 cm
Max. field	1.5 T
K_{max}	35
Wiggler length	4 m
length of DW section	40 m
Critical energy	37 keV
Flux density (one DW)	$2.8 \cdot 10^{15}$ ph/s/mrad^2/0.1%BW

Reduction of vertical emittance by optimizing storage ring parameters

25 pm

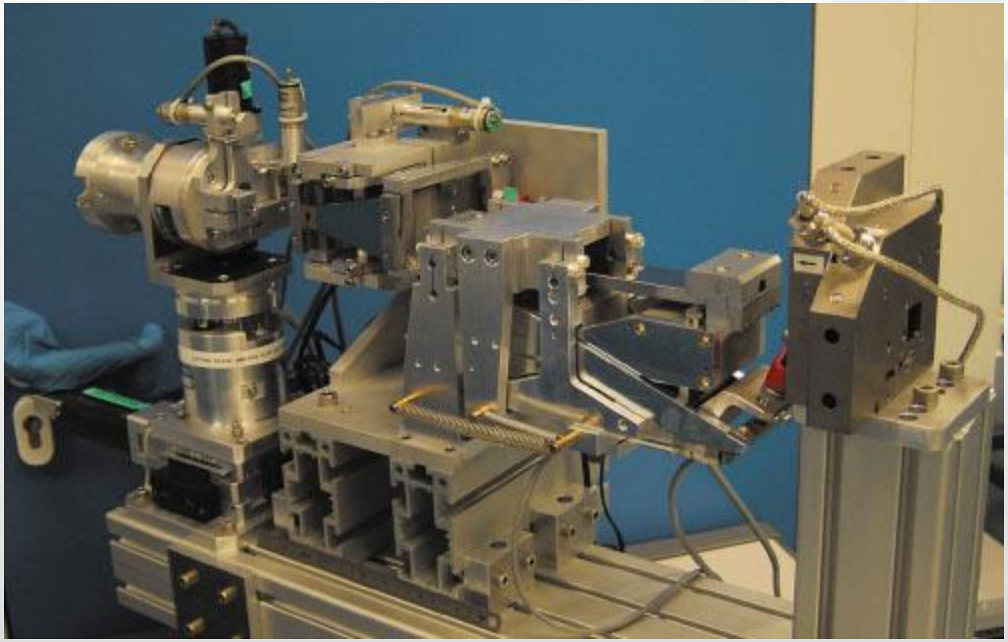
5 pm (today)

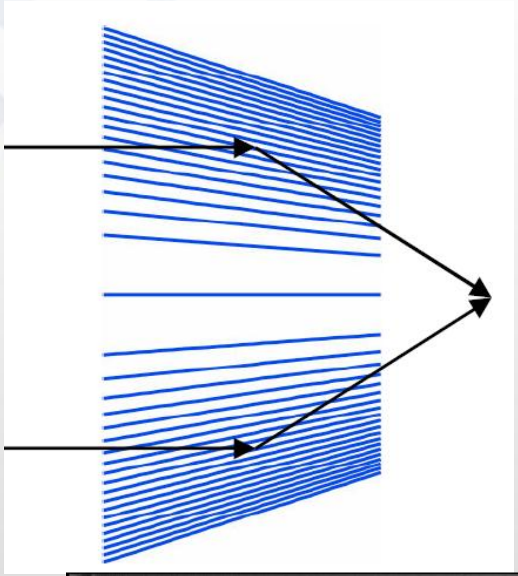
2-3 pm (2012)

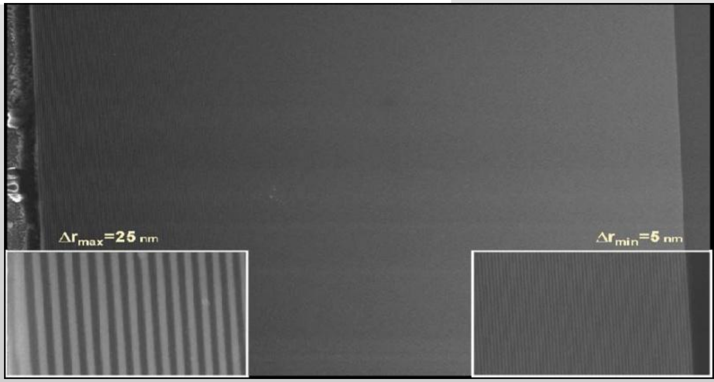


Focusing optics

MLL lenses



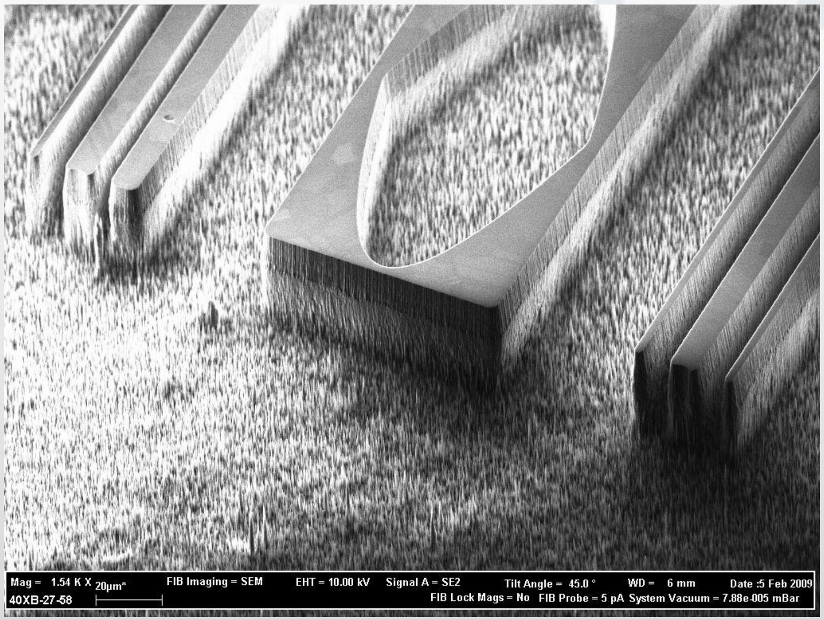




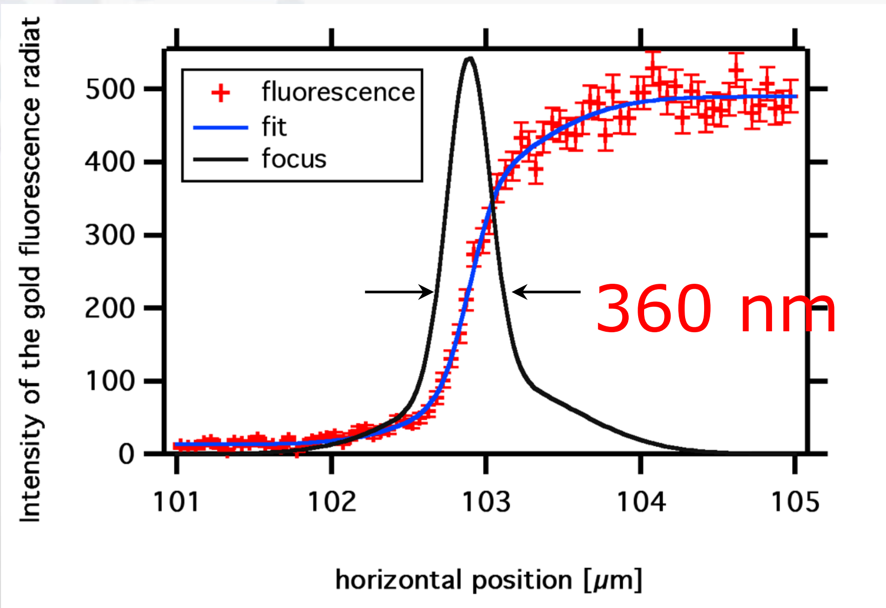
KB optics

goal: stable focused beams down to ~ 1 nm

Nanofocusing with Diamond Lenses



E-beam lithography & Deep RIE



Tests of 2009 generation of C lenses

Long Term Collaboration with
TU-Dresden, C. Schroer et al.

Lens production:
Fraunhofer IAF and
Diamond Materials.

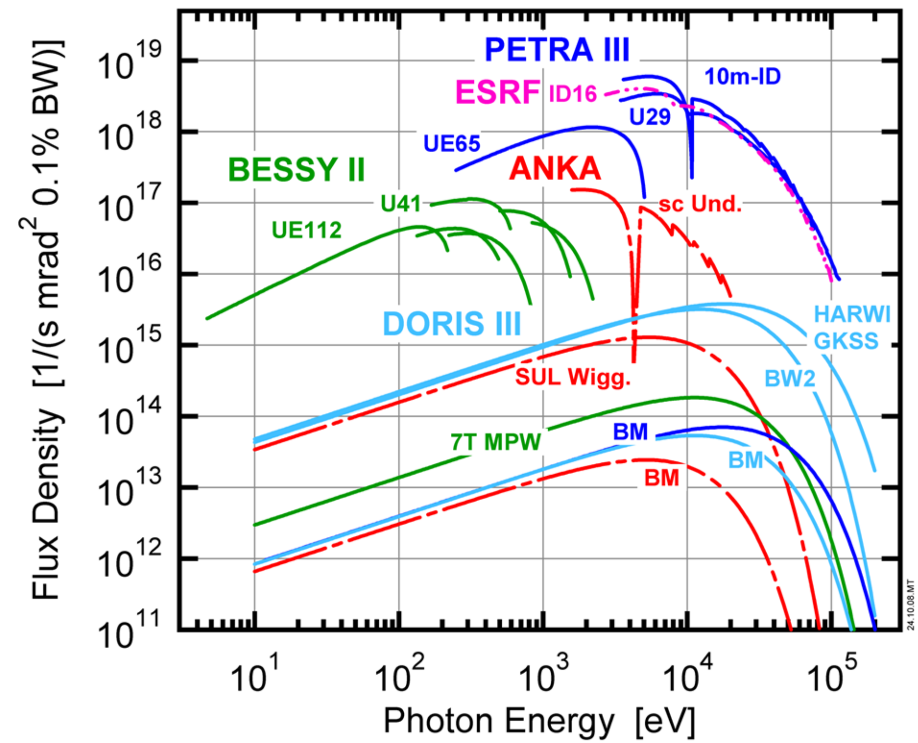
PETRA III

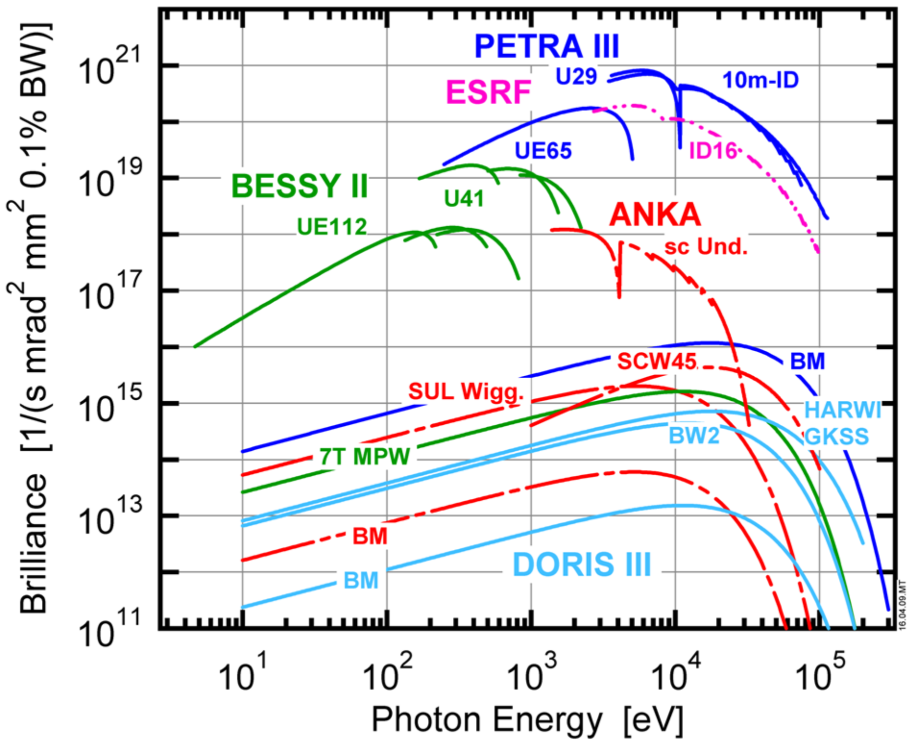
- rebuild of 1/8 of the 2304m circumference
- refurbishment of 7/8 of the storage ring
- refurbishment of pre-accelerator chain (also used by DORIS III)
- construction of a 300m long new experimental hall
- installation of 80m of damping wigglers
- top up operation mode

key parameters:

- particle energy:	6GeV
- current:	100mA (200mA)
- horizontal emittance:	1 nmrad
- No. of undulators:	14 (incl. canted)
- undulator lengths:	2-10(20) m

- no bending magnet beamlines





Photon beam parameters at 12keV:

	β_x [m]	β_y [m]	σ_x [μm]	σ_y [μm]	$\sigma_{x'}$ [μrad]	$\sigma_{y'}$ [μrad]	ID-length [m]
low-β 5 m	1.3	3	35.9	5.7	28	5.0	5
high-β 5 m	20	2.38	141	5.2	8.6	5.2	5

coherent flux:
- 12keV ($B(\lambda/2)^2$)
- 1×10^{11} ph/s/0.01%BW

Horizontal β-function of each straight section can be selected individually and is changeable (β_x= 1.3m or β_x = 20m)

NSLS II

Ultra-low emittance storage ring to replace NSLS

NSLS-II Design Features

Design Parameters

- 3 GeV, 500 mA, top-off injection
- Circumference 791.5 m
- 30 cell, Double Bend Achromat
  - 15 high-β straights (9.3 m)
  - 15 low-β straights (6.6 m)

Novel design features:

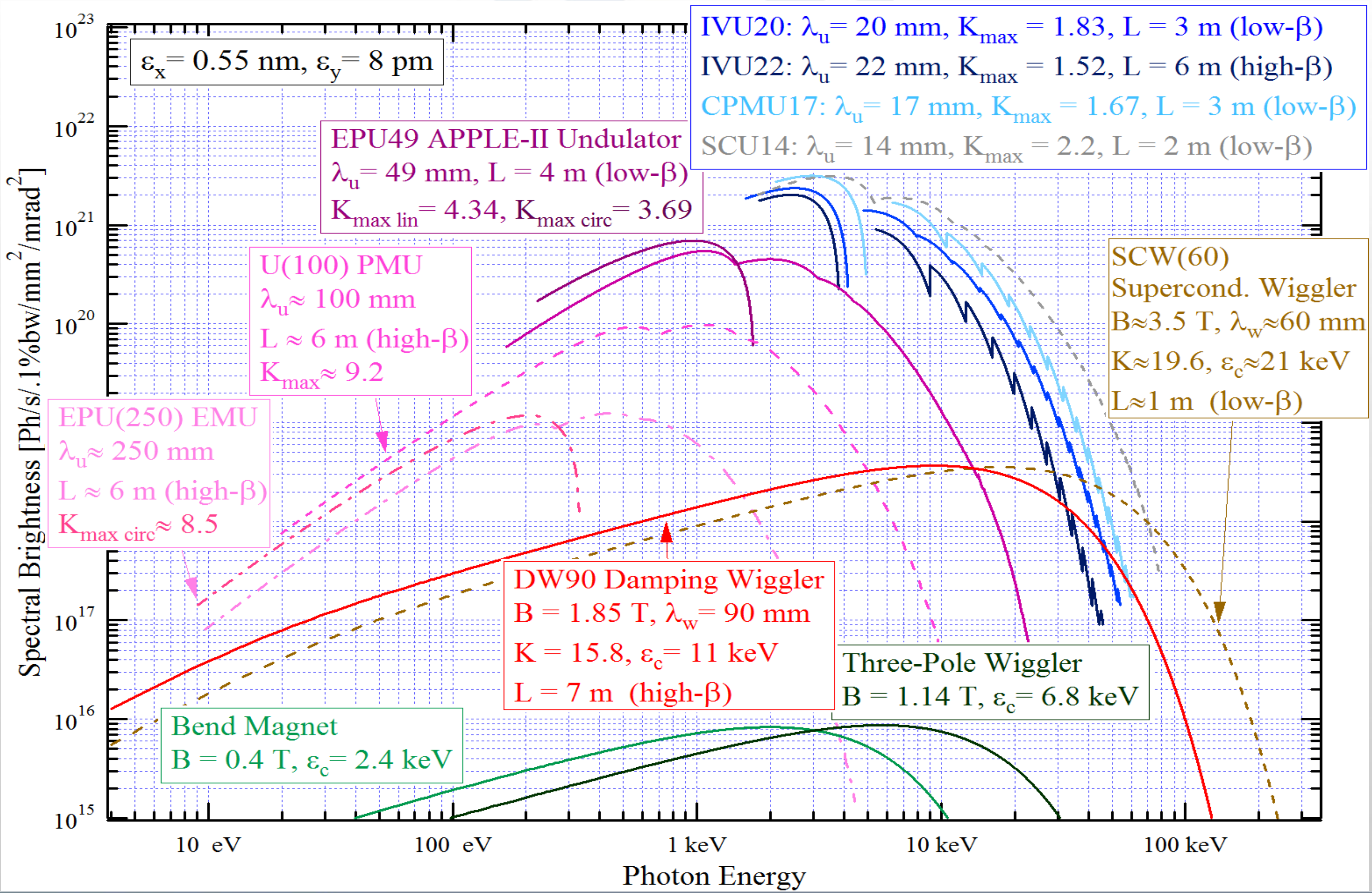
- Damping wigglers
- Soft bend magnets
- Three pole wigglers
- Large gap IR dipoles

Ultra-low emittance

- ε_x, ε_y = 0.6, 0.008 nm-rad
- Diffraction limited in vertical at 12 keV
- Small beam size: σ_y = 2.9 μm, σ_x = 33 μm, σ'_y = 2.7 μrad, σ'_x = 16 μrad

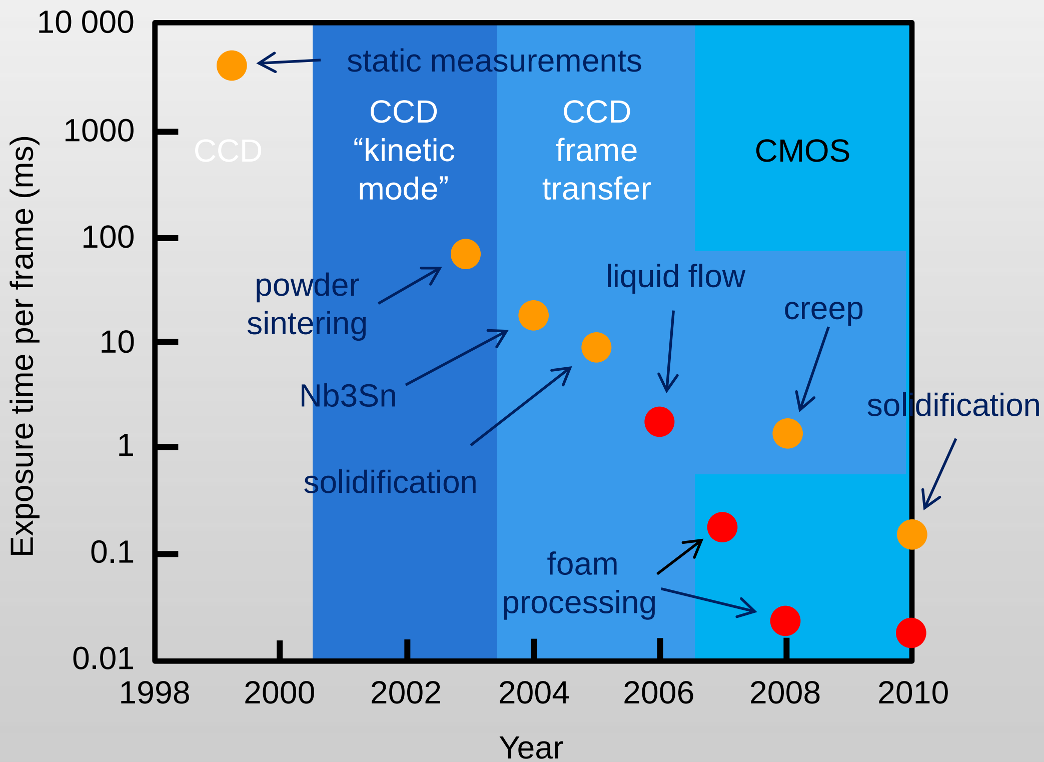
Pulse Length (rms) ~ 15 psec

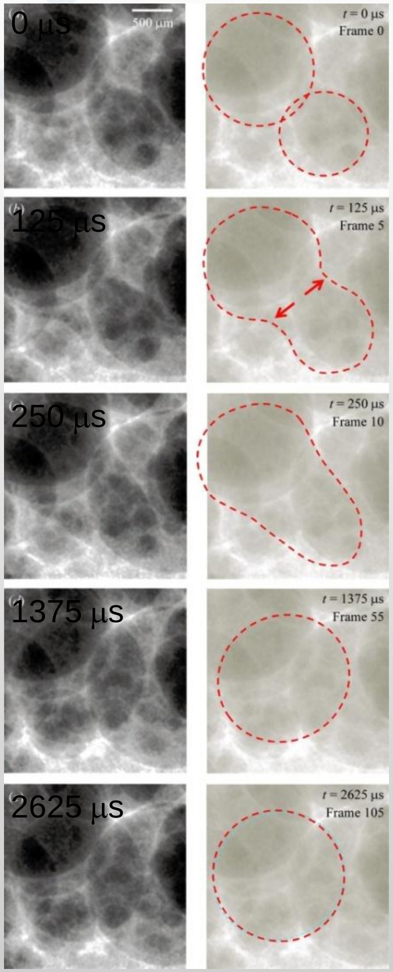
Spectral Brightness of NSLS-II Sources



History of fast imaging (at ESRF)

Shortest detector exposure time
- spatial resolution 1-2μm
- spatial resolution 10-20μm





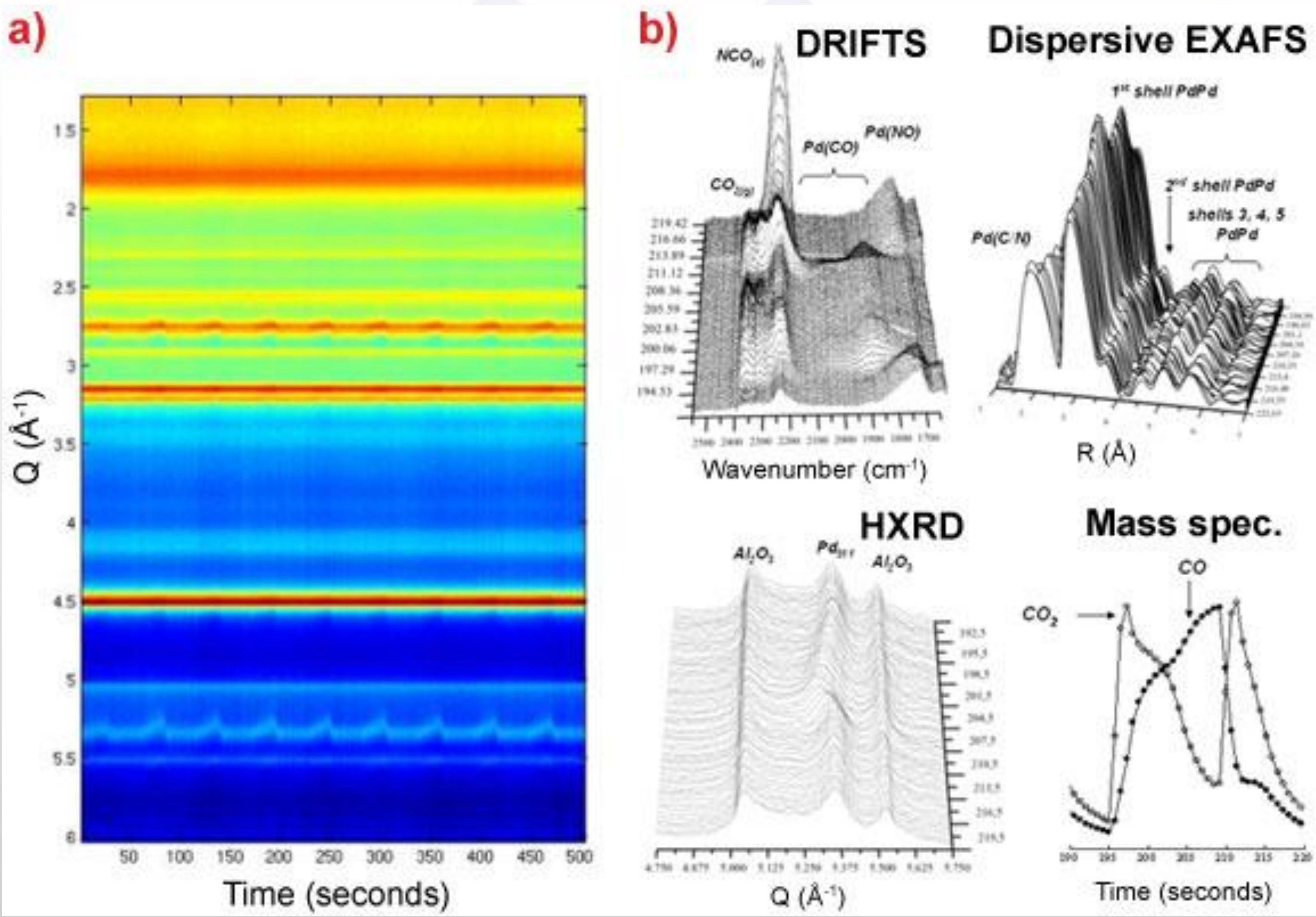
A. Rack et al., JSR 16 (2009)

Combination of techniques

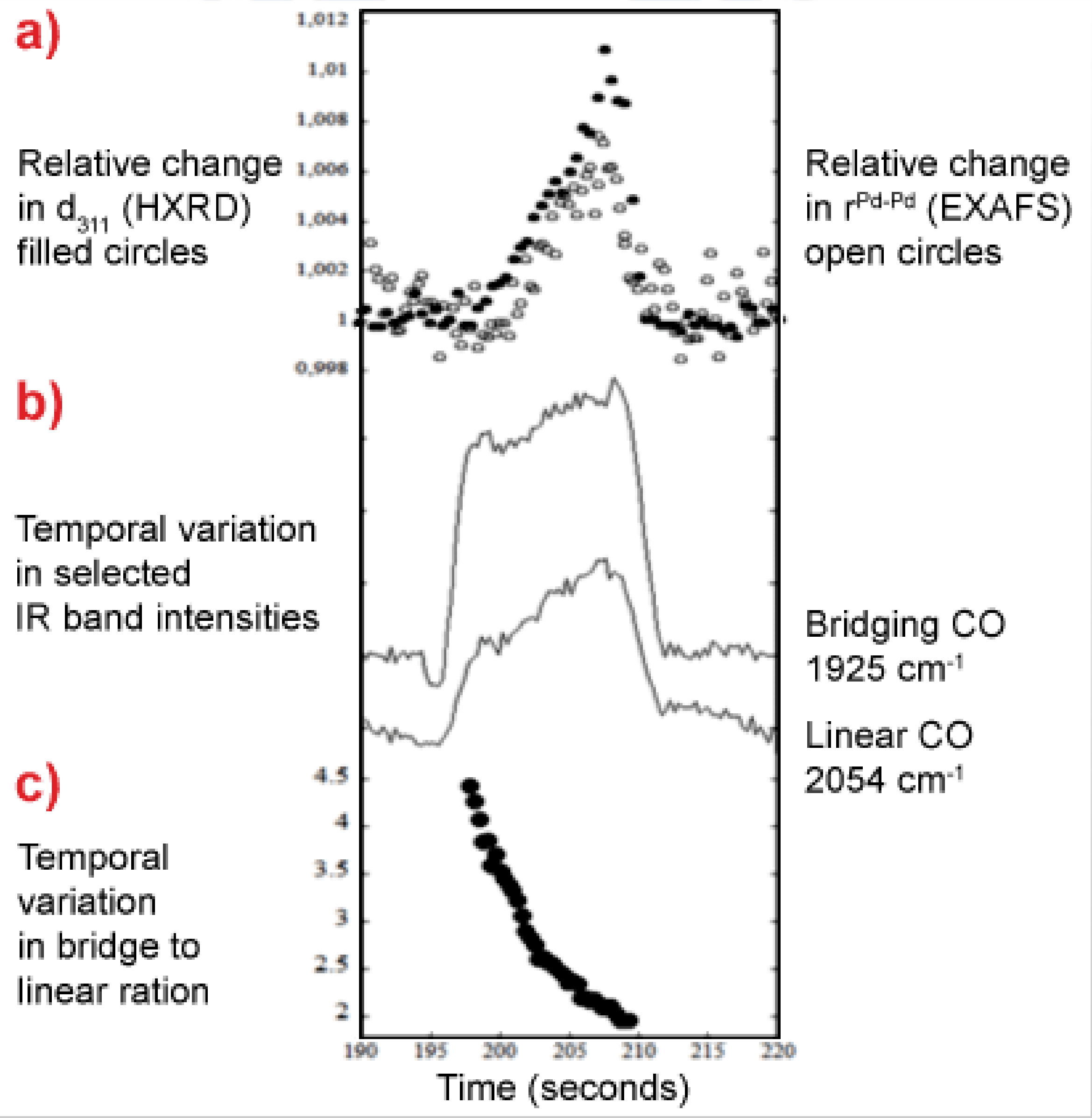
Time-resolved X-ray diffraction and diffuse reflectance infrared spectroscopy to study CO dissociation and transient carbon storage by supported Pd nanoparticles during CO/NO cycling

(XRD –EXAFS – DRIFTS – MS)

M.A. Newton, JACS 132, 4540 (2010)
A. Kubacka et al. *J. Catal*. 270, 275 (2010)



Supported Pd nanoparticles (2wt%Pd/Al_2O_3)
during CO/NO cycling at 673 K (10 cycles)


a)
Relative change in d311 (HXRD) filled circles
1,012
1,01
1,008
1,006
1,004
1,002
1
0,998
Relative change in rPd-Pd (EXAFS) open circles
b)
Temporal variation in selected IR band intensities
Bridging CO 1925 cm-1
Linear CO 2054 cm-1
c)
Temporal variation in bridge to linear ration
4.5
4
3.5
3
2.5
2
190
195
200
205
210
215
220
Time (seconds)